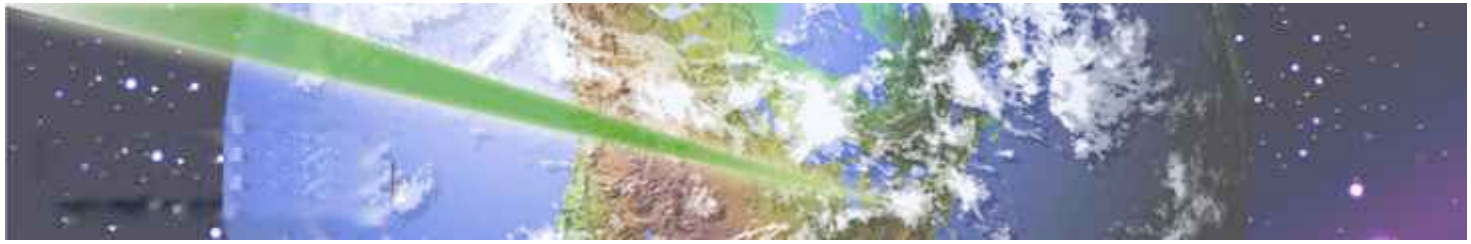

Satellite Laser Ranging Concept Review

Proposed Replacement System

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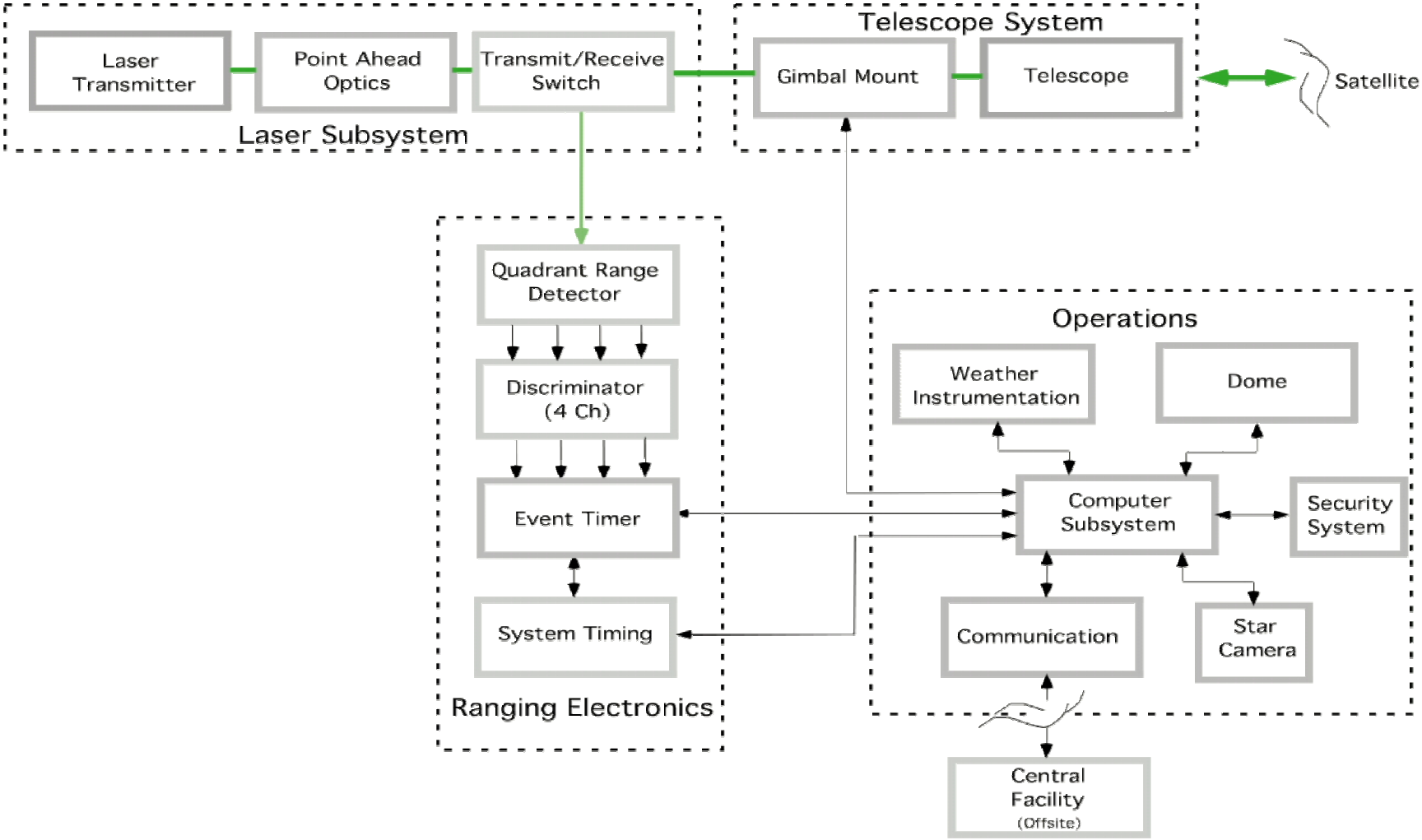
Replacement System Tracking Objectives and Requirements

- Unmanned, autonomous operation at 532nm wavelength
- One cm single shot ranging (1 RMS)
- ~1 mm precision normal points to LAGEOS
- 24/7 laser tracking operations to CCR satellites to 20,000 km
- Free of optical, electrical, and chemical hazards
- “Smart” weather instrumentation to access tracking conditions
- Automated two-way internet communications
- Central facility monitoring of all data products
- Low maintenance and increased reliability
- Reduced system replication cost and system operations cost
- Easily upgraded as new instrumentation becomes available

Replacement System Software Requirements

- **Software must be able to operate on its own**
  - Get predictions (in ILRS specified format) and generate schedule.
  - Know weather and sky conditions and respond to them (dome control and what objects to track).
  - Determine if tracking, and calculate biases needed to optimize tracking.
  - Know system health and security and be able to communicate this information to the Central Facility.
  - Monitor own system performance and schedule calibrations if needed and send system report in daily to Central Facility.
  - Periodically calibrate the pointing by performing star calibrations.
  - Determine system delays to all four quadrants using ground ranging hourly.
  - Calculate normal points for all satellite passes (using specified software package) and transfer them to Central Facility in near real-time.
- **Software must be able to switch to remote operation**
  - Operate automated until remote operator “connects” via internet.
  - Display and control to remote operator.

Simplified SLR Block Diagram



Why Range at 532 nm?

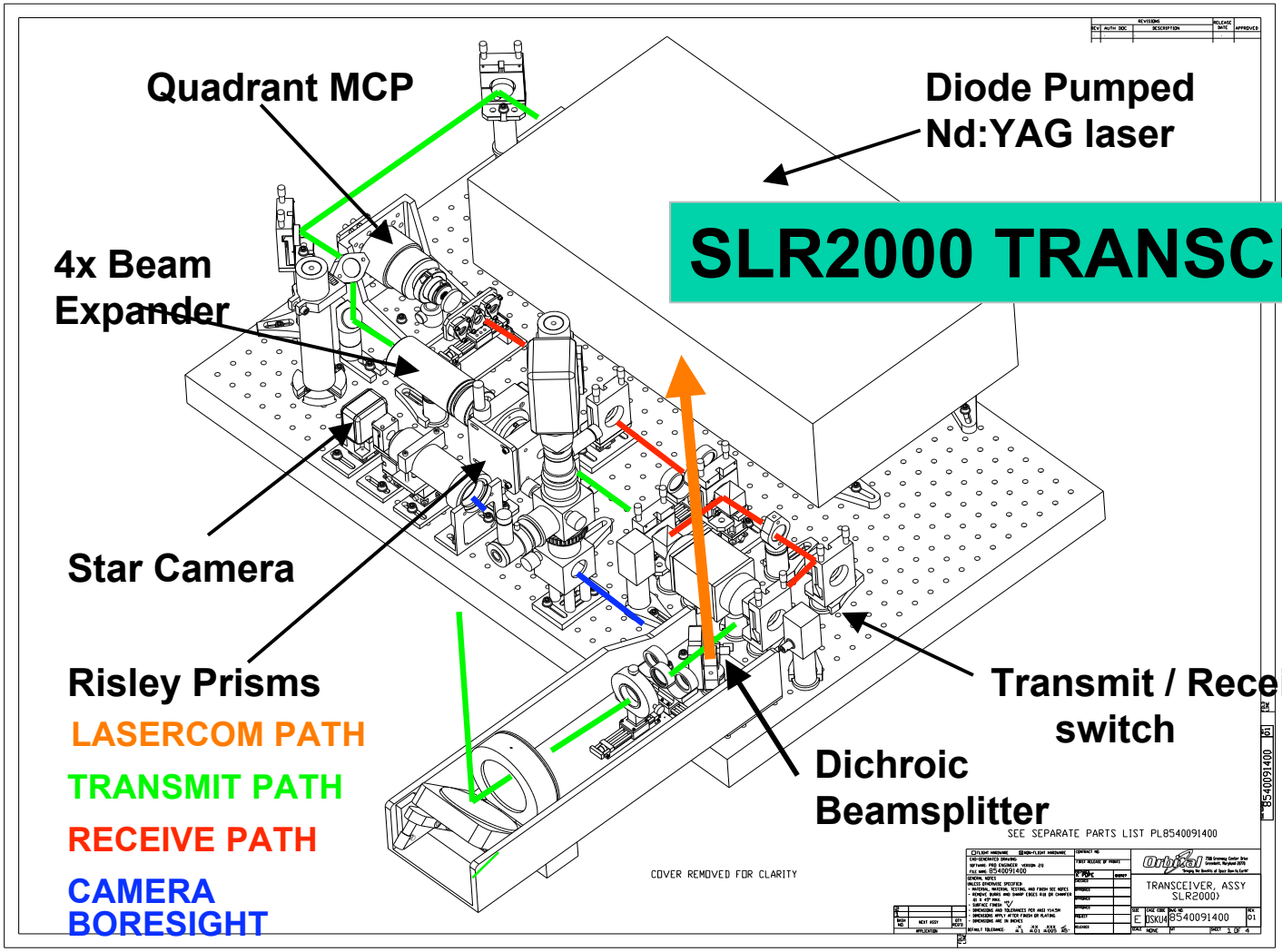
- Passively Q-switched microchip Nd:Yag lasers are a mature and commercially available technology; no other pulse source has a comparable heritage
- Photon-counting efficiencies of detectors at 532 nm are typically an order of magnitude (or more) higher than at 1064 nm
- Spectral filters at 532 nm have higher optical throughputs for a given bandpass than those at 1064 nm.
- The 532nm receiver uses a large active area (6 mm) receive photomultiplier with less complicated quadrant detection optics and electronics (relative to 1064 nm).
- OSHA standards limit the allowable eye exposure for the 1064 nm wavelength to about 1/3 times that of 532 nm because it is not visible.
- 95% of the approximately 40 SLR stations use 532 nm as their wavelength of choice
- Will support future applications which include LaserCom and Transponder

Additional Optical Tracking Applications for Next Generation SLR Systems

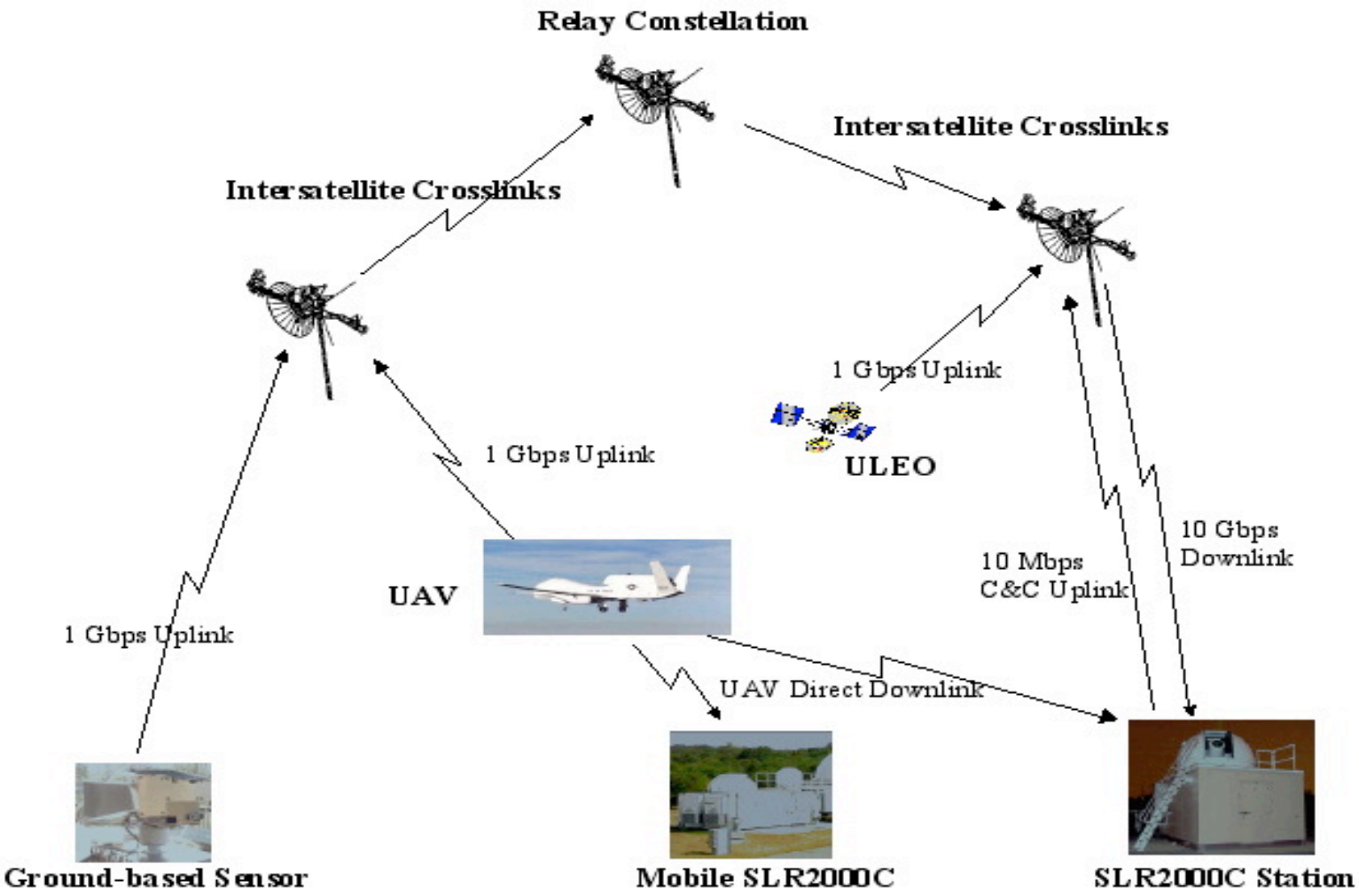
- **Recently concluded Goddard/JPL study suggests SLR2000 with the appropriate upgrades is a viable 2.4 Gb/channel LaserCom terminal for LEO and GEO platforms**
  - Modest upgrade of SLR2000 with COTS Lasercom items at 1550nm: ~$700K additional per terminal
  - Minimal impact between SLR and Lasercom modes
  - Dual mode operation with the SLR function (or remote transponder) can be used as the Lasercom tracking beacon

- **A next generation SLR can be operated as a planetary laser transponder to range at lunar distances and beyond**
  - Robust signal levels at Mars distances are expected
  - Tracking at the few cm level out to planetary distances

The SLR2000 Transceiver Table is Easily Upgraded to Support LaserCom



SLR2000 could become the cornerstone of NASA's next Communication Network



SLR2000 LaserCom Design Approach

- Use COTS components adopted from the telecom industry at1550nm (Large competitive selection of transmitters, detectors, filters, splitters, etc.)
- SLR2000 can track satellites over a wide range of altitudes, and hence, can support a wide variety of spaceborne LaserCom architectures
- Modest 40 cm off-axis telescope has sufficient aperture to handle high bandwidth (2.5 Gb/channel) optical com, yet it is less sensitive to atmospheric perturbations which cause larger telescopes to require adaptive optics
- Closed loop arcsecond precision tracking of CCR equipped com satellites and planetary transponders is expected
- Ground-based SLR serves as a strong beacon for the spaceborne terminal
- Wavelength-Division Multiplexing (WDM) can be used to increase the capacity
- COTS approach holds the differential replication cost to about $700K per system above the cost of a basic SLR2000

SLR2000 as a Transponder Terminal Extends Ranging to Interplanetary Distances

- Because of the $1/R^4$ space loss encountered in SLR, Transponder Terminals ($1/R^2$) become very attractive when at Lunar distances and beyond
- Multi-kHz ranging systems can transfer data to each other by time tagging all transmit and photon receive events at both ends of the link and solving for the range
- Lasers are not required to be at the same rate or wavelength
- Range can be determined to a few cm and clock offsets can be determined between systems in post processing
- At Mars distances (.5 to 1.5 AU) SLR2000-type systems would yield range measurements at a rate of ~ 20 to 4000 per minute, with an accuracy of a few cm
- At Lunar distances SLR2000-type systems would receive data on every fire (120,000 per minute)
- SLR2000 H/W modifications are minimal with a photon counting Multi-Channel Analyzer (MCA) needed to search for the remote signal in time

Conclusions

- **Building on what we have learned from the past, we have designed, built and demonstrated a prototype system for the next generation NASA SLR:**
  - Single photon detection with cm ranging accuracy
  - Means of providing closed loop tracking operations
  - Laser hazards have been eliminated
  - Signal detection algorithms have been shown to recognize extremely low signal levels in the presence of noise.
- **The SLR2000 prototype system is a culmination of many man-years of engineering effort. Completion of the prototype would:**
  - Provide considerable risk mitigation in the replication effort
  - Ensure a less costly more reliable replacement network, and
  - Can be completed without impacting the procurement schedule